

CubeSat Propulsion: AMSAT's Future Self-Propelled Spacecraft

Cameron Castillo

AMSAT Engineering Team

camstillo2000@gmail.com

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1 Propulsion Fundamentals

2 Propulsion on CubeSats

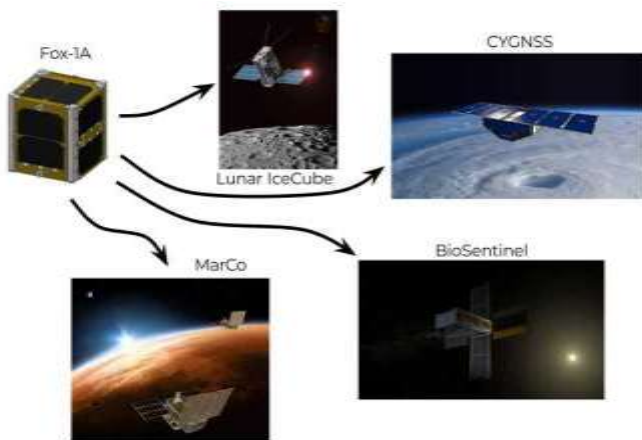
3 Types of Systems

4 AMSAT's (New) Propulsion Work



What is a Cubesat?

Recent CubeSat advancements have made more missions possible.



Propulsion on CubeSats



Figure: The CubeSat Ambipolar Thruster (CAT) from the University of Michigan

- Propulsion systems enable orbit changes in space.
- Minaturized thrusters have lagged behind other development areas.
- Propulsion is necessary for increasingly ambitious CubeSat requirements.



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Phase-3D (AO-40)

- Designed and launched 1994-2000 by AMSAT DE 12/13/2000: 400N chemical thruster **explodes!**
 - ▶ 160,000 joules released
 - ▶ Several power and RF functions disabled
- What does propulsion development look like after AO-40?

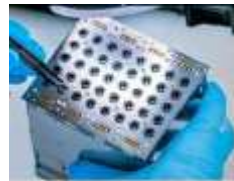
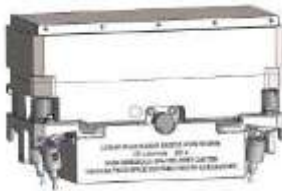
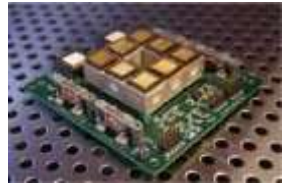


Figure: AO-40 in development



Advancements in Cubesat Propulsion

Propulsion has come a long way in 25 years!



Characterizing Propulsion Mathematically

A propulsion system is defined with three parameters:

Delta-v (ΔV)

general case: $\Delta v = \int |\mathbf{v}| dt$ single-direction: $\Delta v = |v_f - v_i|$ Measure of thrust

necessary for a given orbital maneuver (m/s).



Characterizing Propulsion Mathematically

A propulsion system is defined with three parameters:

Specific Impulse

$$I_{sp} = \frac{I}{m \cdot g_0} = \frac{F}{m \cdot g_0} = \frac{V_e}{g_0}$$

Measure of weight efficiency for a propulsion system (s).



Characterizing Propulsion Mathematically

A propulsion system is defined with three parameters:

Thrust

$$T = \dot{v} \, dm$$

Measure of propulsive force for a burn (N).



Types of Propulsion Systems

Propulsion systems are generally placed in two categories.

Non-electric ○ Low specific impulse. ○ High thrust. ○ Low power consumption. ○ Physically large.

Electric

○ High specific impulse. ○ Low thrust.
○ High power consumption. ○ Physically small.



Non-Electric: Solid

Solid propulsion uses combustion of solid propellants to expel gas.



Figure: Solid propellant test of cubesat frame.

Characteristics

$I_{sp} \ll 100-270$ s • Max Thrust $\ll 76$ N • Complexity: Medium • Flight Heritage: Low • Volume & Mass: High



Non-Electric: Liquid

Liquid propulsion uses chemical reactions to produce heated gas.



Figure: Commercially available bipropellant systems enable high thrust in a small volume.

Characteristics

$I_{sp} \ll 200-450$ s ○ Max Thrust
~ 1.1 N ○ Complexity: High ○
Flight Heritage: Low ○ Volume &
Mass: High



Non-Electric: Cold-gas

Cold-gas systems expel gasses stored in a pressurized tank.

Characteristics ○ I_{sp} & 10-200 s ○

Max Thrust ~ 50 mN ○

Complexity: Low ○ Flight

Heritage: High ○ Volume & Mass:
Medium

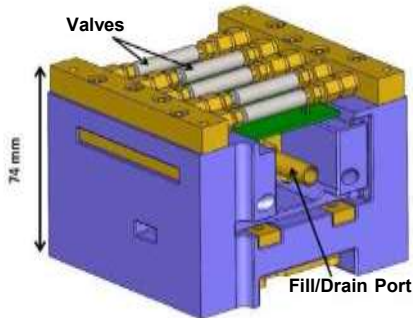


Figure: Additive manufacturing techniques allow for increased complexity without significant risk or cost.

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Non-electric: Solar Sail

Solar sails are propelled by solar radiation pressure.

Characteristics

◦ $I_{sp} \ll TO$

◦ Max Thrust $\wedge 0.8 \text{ mN}$ ◦

Complexity: Medium ◦ Flight

Heritage: Medium ◦ Volume &

Mass: High

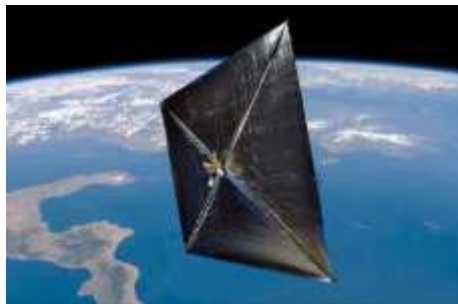


Figure: Several CubeSats have used solar sails successfully in orbit.

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Electric: Hall-effect

Hall-effect thrusters use circulating electrons to ionize particles.

Characteristics $I_{sp} \sim 300\text{-}1750$ o

Max Thrust ~ 50 mN o Complexity:

High o Flight Heritage: Medium o

Volume & Mass: High

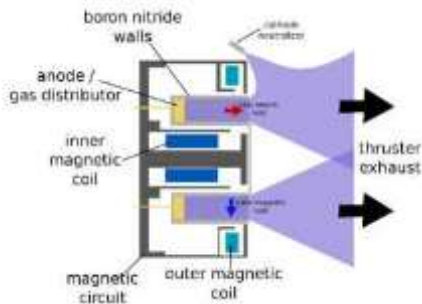


Figure: Although providing high performance, Hall thrusters are extremely complex.

* $\rightarrow X < 2$

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Electric: Electrospray

Electrospray propulsion pulls ions off the surface of a liquid.

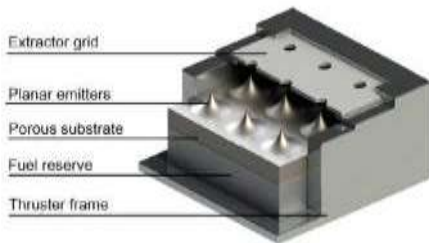


Figure: Miniature electrospray devices can be manufactured reliably.

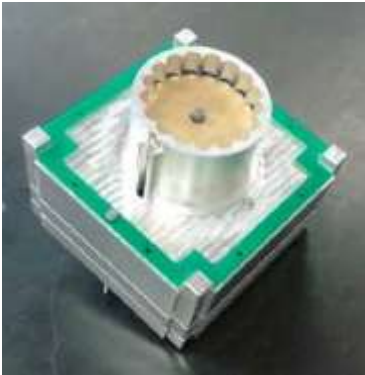
Characteristics

I_{sp} - 800-2500 s ◦ Max Thrust —
2 mN ◦ Complexity: Low ◦ Flight
Heritage: Medium ◦ Volume &
Mass: Low



Electric: Pulsed Plasma

Pulsed plasma thrusters electrically ablate and ionize propellant.



Characteristics « I_{sp} « 900-2400

s a Max Thrust « 0.2 mN a

Complexity: High a Flight Heritage:

Low a Volume & Mass: Medium

Figure: Pulsed plasma thrusters benefit from cathode serration.



Summary of Propulsion Systems

The characteristics of different systems can be summarized:

Type	Specific Impulse [s]	Max Thrust [mN]	Complexity	Flight Heritage
Solid	100-270	76000	Medium	Low
Liquid	200-450	1100	Medium	Low
Hybrid	200-300	22000	High	Low
Cold-gas	10-200	50	Low	High
Electrospray	800-2500	2	Low	Medium
Hall-Effect	300-1750	50	High	Medium
Pulsed Plasma	900-2400	0.2	Medium	Low
Solar Sail	TO	0.8	Medium	Medium



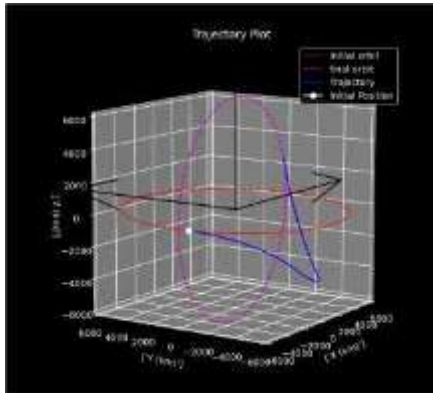
What's New in AMSAT Propulsion?

- Propulsion team newly formed under ASCENT projects.
- Goals of the team:
 - ▶ Researching feasible methods of propulsion
 - ▶ Determining mission capabilities via simulation
 - ▶ Testing hardware and validating technologies
 - ▶ Reaching out to potential industry partners



Figure: Demonstration hardware from an industry partner. ^

Trajectory Simulation



- Started with handwritten Python trajectory optimizers.
- Simulated a few types of transfers, but compute time was very long. Working at simulations in D2S2 for better accuracy.

Figure: Fox-1A Equatorial-Polar Simulation.



Electric Propellants

o Electrically controlled solid propellant (E-propellant). o Ignited only with electric current; otherwise inert. o Multiple integration challenges:

- ▶ Electric load is unstable and hard to drive.
- ▶ Difficult to mix and package.
- ▶ Burn can be uneven if done incorrectly.

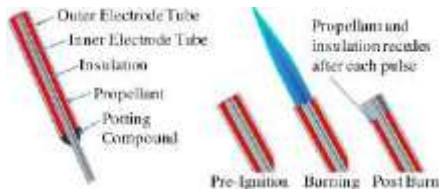


Figure: E-propellant could revolutionize solid-fuel propulsion



Steam Propellants

STEAM vs CHEMICALS ♦ Same Orbit, Different Approach



Figure: Water-based propellants vs chemical

- o Working with industry partners to purchase commercial water-based unit (low-cost).
- o Determining integration necessities surrounding GOLF bus.
- o Simulations and models of thrust to determine feasibility of missions.



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Deployable solar panels often cannot meet propulsion demands

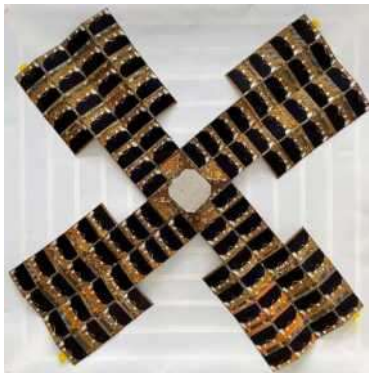


Figure: A commercially available 100W deployable solar array.

- The largest 3U deployable panels generate 20W average.
- Deployable solar arrays could provide more power.
- Complexity and size limit integration.



How do we avoid another AO-40?



Figure: CubeSats like PTD-1 successfully demonstrated new propulsion tech.

- We allow more risk than commercial operations ▶ Critical subsystems must be kept safe in failure
- Many distributors are willing to work with us

- ▶ Get flight history for new technology
- ▶ Minimal cost to AMSAT for system



You could be at the forefront of AMSAT's propulsion development!

○ Skills Needed:

- ▶ Power supply design
 - ▶ Control systems
 - ▶ Simulation software development
 - ▶ Trajectory optimization
- AMSAT's future relies on **propulsion!**

